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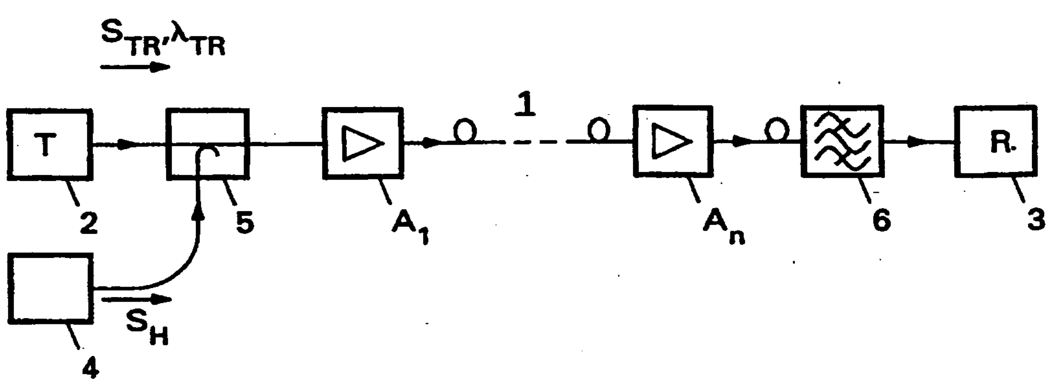

(57) Abstract

An optical system for long-distance transmission of intensity-modulated optical signals comprises an optical transmitter (2) and an optical receiver (3) connected to an optical-transmission line (1). In the transmission line, there is included a row of one or more cascaded semiconductor optical amplifiers (A_1, ..., A_n). A transmission signal (S_{TR}) generated by the transmitter (2) is combined, in an optical combinator (5), with an optical help signal (S_H) generated by an optical-signal source (4) which is separated, just before the receiver (3), from the transmission signal by optical-separating means (6). The help signal has an optical power for attenuating the ER degradation in the modulated transmission signal in the event of amplification in the row of optical amplifiers. Various options for the help signal are offered. The power of the help signal is preferably tuned to the maximally permissible ER degradation and gain degradation per amplifier.

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Optical long-distance signal transmission with optical amplification.

A. BACKGROUND OF THE INVENTION

1. Field of the invention

The invention lies in the field of signal transmission along long-distance optical connections. More in particular, it relates to a method and a system for transmitting intensity-modulated optical signals along a long-distance optical connection in which there are included one or more optical semiconductor amplifiers.

2. Background art

Amplification of digitally modulated optical signals in optical connections is preferably effected using optical amplifiers. After all, said amplifiers have the advantage that they do not depend on the bit rate and the modulation format, such contrary to amplifiers based on an optical receiver/transmitter combination, in which there is used a double signal conversion between the optical and the electrical domain. One type of optical amplifier is the EDFA (erbium-doped fibre amplifier) which is pumped with the light of a semiconductor laser. This type of optical amplifier requires an additional laser-light source, and is not compact and low-energy. Another type of optical amplifier is based on the semiconductor laser itself, which type hereinafter will be denoted by SOA (Semiconductor Optical Amplifier). The SOA currently is the smallest and most low-energy type of optical amplifier, and potentially also the cheapest. Still, the SOA has a number of restrictions, as a result of which, in the event of long-distance connections (typically ≥ 50 km), it cannot be applied just like that to the mutual distances to be expected on the grounds of the attainable gain and of the noise behaviour, and not in an unlimited number in succession. Such has already been disclosed in the patent publication US-A-4,995,100. One of said restrictions is the sensitivity to the ambient temperature, as a result of which the gain of the amplifier is adversely affected. In the patent publication referred to above, said restriction is eliminated by adding, to the optical signals to be amplified along the way, upon first generation, a low-frequency control tone as an additional corrugation on the carrier beam of, and the data in, the optical signals. Each SOA along the way is additionally provided with an AGC circuit (AGC = Automatic Gain Control), in which said corrugation is measured and used as a parameter for regulating the gain of the SOA in

situ. Another problem of the SOA, particularly for intensity-modulated optical signals, which in said publication is not broached, is the problem known as extinction-ratio degradation, hereinafter to be referred to as ER degradation, as a result of the fact that the gain of an SOA may vary considerably in the event of a variation in the input power. Said problem of the ER degradation as a result of gain variation is explained with reference to the figures FIG. 1, 2 and 3. FIG. 1 shows a graphical representation of a typical course v of the gain G of an SOA as a function of the input power P. As a result of saturation effects, said course is such that the gain decreases with increasing input power. In an optical signal modulated with binary data, the signal power in the "0"/"1" and in the "1"/"0" transitions switches between two levels, e.g., a low level P_0 for the digital "0", and a high level P_1 for the digital "1". The ratio between the high and the low level is known as the extinction ratio ER = P_1/P_0, which is used as a measure for the distinguishability of the two levels. To the two levels, there correspond distinct values for the gain, namely, G_0 and G_1, and moreover $G_0 - G_1 = \Delta G > 0$. The recovery time for the gain of an SOA under intensity changes lies in the order of 200 ps, while the bit duration, e.g., for bit rates of 311 Mb/s is in the order of 3000 ps. This means that, as ΔG increases, the optical gain for the two levels may differ significantly; namely, to such an extent that the extinction ratio ER after amplification by an SOA is lower, even significantly lower, than before. In the event of higher bit rates, where the bit duration is similar to, or less than, the gain-recovery time, the ER degradation manifests itself as a deformation of the bit pattern. FIG. 2 shows an example of a deterioration of the extinction ratio after amplification by an SOA. Component (a) of FIG. 2 shows part of a bit pattern at the input of an SOA having an extinction ratio ER = 10 (P_0=1, P_1=10). Component (b) shows the same pattern at the output of the SOA. In this connection, the "0" level and the "1" level underwent different gains (by a factor 20 and 10, respectively), and the extinction rate is lowered to ER' = 5. A customary measure for the ER degradation is ERD = -10log(ER'/ER) dB, which in this example has the value of 3 dB. The ER degradation, however, depends on the input power. FIG. 3 shows the course w_1 (* curve) of the ERD measure (dB) for the degradation, as it was obtained from a simulation, as a function of the average input

power P (dBm) with the ER of the input signal being kept constant (10 dB). The course w_1 of the ERD measure shows that, if an ER degradation of 2 dB in a connection with one SOA is deemed acceptable, the signal power at the input of said SOA must be less than -9 dBm. For a connection having a number of n cascaded SOAs, this would mean that on average the ER degradation per SOA must not be in excess of 2/n dB. In the event of an increasing n, an ever decreasing, but still permissible, ER degradation, however, corresponds to an ever decreasing input power (see once again curve w_1 of FIG. 3). On a long-distance connection, a number of cascaded SOAs will be capable of sufficiently compensating for the optical attenuation in the connection. If in this connection the ER degradation must be restricted as much as possible, only a correspondingly restricted input power per amplifier is permissible, with the resulting unfavourable signal/noise [S/N] ratio at the output of each amplifier. This means that the ER degradation is capable of being restricted only at the expense of a deterioration of the S/N ratio. In the event of an increasing number of SOAs in an optical connection, therefore, either the ER degradation or the S/N ratio will become so unfavourable that the detection of a digitally modulated optical signal becomes unreliable or even impossible.

In the patent publication EP-A-0572890 there is disclosed an optical demultiplexing system in which use is made of a characteristic property of an SOA. Said property implies that, if an intensity-modulated optical signal is combined with an unmodulated optical signal, and the combined signal is subsequently amplified in an SOA, as a result of a saturation effect the gain of the amplifier is modulated according to the algebraic sum of the powers of the two combined signals. In other words, the gain of an SOA varies as a function of variations in the input power. As a result of such a gain variation, the original unmodulated signal is modulated as well, viz., in an inverted form with respect to the originally modulated signal. Said phenomenon of gain variation occurs independently from the fact whether, and how, the optical power is distributed among different wavelengths. The known system makes use hereof for realising a demultiplexing function, with signal samples in a certain time slice of an optical TDM data signal being capable of being split off from an optical TDM-data signal. This is achieved by combining a TDM-data

signal of a first wavelength with an optically unmodulated sampling signal of a second wavelength and, after amplification by filter means, carrying out a wavelength separation.

B. SUMMARY OF THE INVENTION

The object of the invention is to provide for a method and a system of the type referred to above, with which and in which it is achieved that the ER degradation per optical amplifier used is significantly less without an appreciable deterioration of the S/N ratio, and as a result of which, therefore, there may be used a greater number of cascaded optical semiconductor amplifiers. The invention is based on the consideration that, by adding additional optical power, which is optically well-distinguishable from the transmission signal proper and/or does not have an interfering effect on the detection thereof at the receiver side, every SOA at its input experiences an optical signal having a fully optical power which proportionally demonstrates much smaller fluctuations than the intensity fluctuations in the modulated signal itself. This means that, due to such an addition, the gain variation decreases and the difference in gain between the two intensity levels in the modulated optical signal is therefore reduced.

Starting from said consideration, a method according to the preamble of claim 1, of a type as known per se from the European patent application discussed above, according to the invention is characterised as in claim 1.

In a preferred embodiment, the optical power of the help signal is chosen as a function of a maximally permissible value per amplifier for the ER degradation and/or gain degradation.

In another preferred embodiment, the power of the help signal is chosen in such a manner that the power of the combined signal at the input of the first amplifier is substantially constant.

In a further preferred embodiment, the help signal is a noise signal generated by an optical noise source. This has the advantage that at the receiver side no specific filters are required to separate the help signal from the transmission signal proper. Furthermore a propagating noise signal, which initially is modulated, and therefore demonstrates a time dependency, after a while loses said time dependency as a result of dispersion and becomes constant. This has

yet another advantage if upon generation the power of the noise signal is given a specific time dependency in order to achieve a constant power of the combined signal at the input of the first amplifier. Said time dependency, which otherwise might have an interfering effect at the input of a next amplifier due to differences in time delay, is no longer present.

Moreover, the invention provides for an optical system according to claim 12.

Further preferred embodiments of the method and the optical system according to the invention are summarised in the subclaims.

The invention makes it possible not only for a greater number of optical amplifiers to be cascaded in a long-distance connection, but also permits greater powers and/or power variations at the transmitter. Moreover, the first amplifier in the row may be a "booster" amplifier, as a result of which the transmitter power may remain restricted, and there need not be used a powerful, expensive transmitter.

C. BRIEF DESCRIPTION OF THE DRAWING

The invention will be explained in greater detail by means of a description of an exemplary embodiment, with reference being made to a drawing comprising the following figures:

FIG. 1 graphically shows a course of the gain typical for a semiconductor optical amplifier;

FIG. 2 in components (a) and (b) schematically shows an intensity-modulated, binary optical signal in which, due to optical amplification, there occurs degradation of the extinction ratio before and after amplification, respectively;

FIG. 3 graphically shows a course, obtained from simulation, of a measure for the degradation of the extinction ratio for a semiconductor optical amplifier, without (* curve) and with (o curve) application of the invention;

FIG. 4 schematically shows a configuration for an optical-transmission system according to the invention;

FIG. 5 schematically shows a variant for part of the configuration according to FIG. 4;

FIG. 6 in components (a), (b), (c), (d) and (e) shows various

wavelength spectra for a transmission signal S_{TR} in combination with a help signal S_H;

FIG. 7 shows a graphical representation of a simulated course of the extinction ratio ER as a function of the length of a transmission line, without help signal added (■ curve), and with help signal added (◆ curve);

FIG. 8 shows a graphical representation of a simulated course of a limit value for the extinction-ratio degradation ERD;

FIG. 9 shows a graphical representation of a simulated course of a limit value for the gain degradation GD;

FIG. 10 for three situations shows the course of the extinction-ratio degradation ERD.

D. DESCRIPTION OF AN EXEMPLARY EMBODIMENT

In FIG. 4, there is schematically shown a configuration for an optical-transmission system according to the invention. To an optical-transmission line 1, in this case an optical-fibre connection, there are connected a transmitter 2 and a receiver 3. The transmitter 2 and the receiver 3 are designed for transmitting and receiving, respectively, an intensity-modulated optical-transmission signal S_{TR}. In the transmission line 1, there is included a number of n semiconductor optical amplifiers $A_1, A_2, \ldots, A_n$. The transmitter 2 generates and transmits the signal S_{TR} at a (carrier) wavelength λ_{TR} and having a power P_{TR}. During the transmission along the transmission line 1, the transmission signal attenuated along the way is amplified in the consecutive optical amplifiers $A_1, \ldots, A_n$. An optical-signal source 4, hereinafter to be referred to as help source, generates an optical help signal S_H, which is combined, by way of an optical combinator 5, with the transmission signal S_{TR} transmitted by the transmitter 2. Between the last amplifier A_n in the row and the receiver 3, there is included an optical separator 6 to again separate the transmission signal S_{TR} from the help signal S_H.

As already described above with reference to the figures FIG. 1, 2 and 3, for each amplification there occurs an ER degradation. Simulation, however, has shown that, if additional optical power is added without interfering with the transmission signal proper at the input of an SOA, said degradation is capable of being considerably

reduced. In FIG. 3, the course w_2 (o curve) shows the result of the simulation. Said course, which was obtained in a similar manner as the course w_1 at an additional input power of -3 dBm, clearly shows a sharp reduction of the ER degradation.

For the help signal, several variants are possible to add additional optical power thereto by combination with the transmission signal S_{TR} without interfering with the information content of the transmission signal, and without substantially aggravating the detection thereof.

In a first variant, the help signal S_H is a CW [continuous-wave] signal having a wavelength $\lambda_H \neq \lambda_{TR}$, having a suitably chosen power (see below). The help source is, e.g., a laser diode. The combinator 5 is, e.g., a 3-dB power coupling or a WDM multiplexer [WDM = wavelength division multiplex]. The separator 6 is, e.g., a narrow-band pass filter for the carrier wavelength λ_{TR}.

In a second variant, the help signal S_H again is a signal having a wavelength $\lambda_H \neq \lambda_{TR}$, but it is complementarily modulated with respect to the transmission signal S_{TR}, and preferably has a power $P_H \approx P_{TR}$. For the rest, said variant may be equal to the first one. Said second variant has the great advantage that essentially there occurs no ER degradation.

In a third variant, the help source 4 is an optical-noise source which generates a noise signal as help signal, such as, e.g., the noise of an optical amplifier. The noise signal has a wavelength band of $\Delta\lambda_N$ within which the carrier wavelength λ_{TR} of the transmission signal lies. As a combinator, there may be used a 3-dB power coupler. For the rest, this variant may again be equal to the first one. The advantages of this third variant are that there need not be generated an additional signal having a specific wavelength, and that the bandwidth of a narrow-band pass filter used as separator 6 may be chosen more freely, or that the separator even becomes superfluous.

In a fourth variant which is a preferred embodiment of the third variant, the noise signal is first conducted through a band-suppressing filter 7, which is rejecting for a narrow wavelength band around the transmission wavelength λ_{TR}, before the combination with the transmission signal takes place in the combinator 5. This is shown in FIG. 5. The advantage of said fourth variant is that no

noise is added at the transmission wavelength.

If, instead of the band-suppressing filter 7, there is chosen a possibly tunable band-pass filter 7', a fifth variant is that the latter only lets pass the part of the noise band which lies below the narrow wavelength band around the transmission wavelength λ_{TR} (or, as a sixth variant, the portion above it). This is shown in the subfigure (a) of FIG. 5.

FIG. 6 with components (a), (b), (c), (d) and (e) for the several variants schematically shows the wavelength spectrum of the transmission signal S_{TR} and the help signal S_H; namely, component (a) for the first variant, component (b) for the second variant, component (c) for the third variant, component (d) for the fourth variant, and component (e) for the fifth variant.

The transmission signal may also be a multiplexed signal of a number of different wavelengths, which lie together in a relatively narrow wavelength band. This is possible remotely outside the wavelength area in which the help signal was chosen, as in the first two variants, but also within or near the noise band $\Delta\lambda_N$, as in the third, fourth and fifth variants. The additionally added optical power of the help signal also reduces a cross-gain modulation possibly occurring in this connection.

In general, it may be stated that there occurs no gain variation if the total optical power at the input of each SOA is constant; therefore, if the sum of the intensities of the transmission signal and the help signal is constant, i.e., $d/dt(I_{TR}(t) + I_H(t)) = 0$. An example thereof is the second variant described above, in which the help signal and the transmission signal have substantially equal powers and are complementarily modulated with respect to one another. The other variants, too, may be constructed in such a manner that the help signal therein is complementarily modulated with respect to the transmission signal. In this connection it should be noted that in a row of SOAs, since the greatest ER degradation occurs at the first SOA, a constant total optical power, particularly at the input of the SOA, will have the maximum effect. Furthermore, the fact should be taken into account that, if a modulated noise signal is used, as a result of dispersion said signal will loose its modulation after a while and become constant. This means that such a noise signal must be generated in

the vicinity of a respective amplifier.

FIG. 7 shows, for a transmission line having 12 amplifiers, the extinction ratio ER as a function of the length L of the transmission line, as this was obtained from a simulation. In this connection, the amplifier A_1 was taken as booster amplifier and the remaining amplifiers as in-line amplifiers, with the mutual attenuation for each line section between two amplifiers always being set at 25 dB. Further parameters chosen:

Power for the help signal: $P_H = P_{TR} + 3$ dB.

For the amplifiers: small-signal gain $G_{ss} = 30$ dB, saturation power $P_{sat} = 10$ dBm, noise factor NF = 10 dB, and filter bandwidth $\Delta\lambda_F = 2$ nm.

For the booster amplifier: average input power $P_{ave} = -5$ dBm.

For the receiver: a Q value > 6 for a BER < 10^{-9}, and an extinction ratio ER ≥ 6 dB.

In the graph, there are shown two curves, a curve x_1 (■ curve) for the course of the extinction ratio ER without a help signal added, and a curve x_2 (◆ curve) for the course with the help signal added. The graph shows that without addition the extinction ratio after two to three amplifiers is already virtually zero, while with the help signal the extinction ratio after the last amplifier still has an acceptable value of 6 dB.

Furthermore, using simulation the maximum permissible power variation of the transmitter was verified for a transmission line having 9 amplifiers and 9 sections, each having an attenuation of 25 dB, with the extinction ratio ER continuing to be ≥ 6 dB and the Q value ≥ 6. Without adding extra power, i.e., without help signal, a variation of only 7 dB proved permissible, while the variation with a help signal having a power $P_H = P_{TR} + 3$ dB, and having a power $P_H = P_{TR} + 6$ dB was permitted to be at least 20 dB.

Favourable results relating to the ER degradation by adding such a help signal may certainly be expected, not only for bit rates in the order of 100 Mb/s, but also for higher bit rates, such as 2.5 and 10 Gb/s. For such higher bit rates, the ER degradation no longer manifests itself per bit, but rather causes undesirable interferences in longer bit patterns.

The course of the gain G, as shown in FIG. 1, however, is such that the gain G for an SOA becomes smaller with increasing power P of

the input signal. This means that the addition of extra power as a result of combining the transmission signal with an additional help signal, is also accompanied by a reduction of the gain. Such a reduction of the gain is known as gain degradation GD. Should f express the power ratio of the power P_H of the help signal and the total power P_{TOT}, then the following may be concluded. To allow the gain degradation GD to be minimal, f must be chosen as low as possible, while for restriction of the ER degradation, f on the contrary must be as high as possible. This means that in the event of a given maximum permissible ER degradation and gain degradation there may be deduced possible values for f.

For both degradations, there may be deduced (strict) limits as a function of f. For a simple model optical amplifier, said limits are:

for the ER degradation:

$$ERD \le MAX(ERD) = 10*Log10*((1/ER+f)/(1+f)) \qquad (1)$$

where ER is the extinction ratio at the input of the amplifier;

and for the gain degradation:

$$GD \le MAX(GD) = 10*Log10*(f+1) \qquad (2)$$

The course of MAX(ERD) as a function of f (at ER=10) is shown in FIG. 8, while the course of MAX(GD) as a function of f is shown in FIG. 9.

Furthermore, in FIG. 10 there is graphically shown, for three values of f, the course of the ER degradation ERD (dB) as a function of the average input power $\underline{P}$ (dBm). The curve y_1 shows this course for a transmission signal without help signal added, i.e., for $f=-\infty$, while the curves y_2 and y_3 show said course for a transmission signal with help signal added, with f=0 dB and f=+3 dB, respectively.

Example: According to FIG. 8, a maximum ER degradation of 1.1 dB per amplifier corresponds to f=+5 dB (point Z_1), which according to FIG. 9 implies a maximum gain degradation of approx. 6 dB (point Z_2). This holds, however, for a worst-case scenario which applies to any input power. If, however, it is also known that the input power (on average) per amplifier is ≤-10 dBm, then there may be chosen f=0 dB (point Z_3 on curve y_2 in FIG. 10). For f=0 dB, the gain degradation

is ≤3 dB (according to FIG. 9).

Thus it is possible, for any given maxima of the input power and the two degradations (ERD, GD), always to determine a suitable f, and therewith a suitable additional power for the help signal.

E. CLAIMS

1. Method for transmitting an intensity-modulated optical-transmission signal, hereinafter referred to as the modulated signal, along an optical-transmission line between a transmitter of, and a receiver for, the modulated signal, in which transmission line there are included one or more consecutive semiconductor optical amplifiers, hereinafter referred to as amplifiers, which amplifiers are provided with a common amplifier band for amplification of the modulated signal during the transmission along the transmission line, according to which method the modulated signal, prior to amplification by one or more of the amplifiers, is optically combined with an optical help signal to form a combined signal, characterised in that the optical signal has an optical power which is tuned to an attenuation of a reduction of the extinction ratio, hereinafter to be referred to as ER degradation, in the modulated signal upon amplification of the combined signal in one or more of the amplifiers.

2. Method according to claim 1, characterised in that the optical power of the help signal is chosen as a function of maximally permissible values per amplifier for ER degradation and/or gain degradation.

3. Method according to claim 2, characterised in that the optical power of the help signal is chosen in accordance with the following two inequalities:

(i) $\mathrm{ERD} \leq \mathrm{MAX(ERD)} = 10*\mathrm{Log10}*((1/\mathrm{ER}+f)/(1+f))$

and

(ii) $\mathrm{GD} \leq \mathrm{MAX(GD)} = 10*\mathrm{Log10}*(f+1)$,

where ER is the extinction ratio at the input of the first amplifier, f is the power ratio between the power of the help signal and the power of the combined signal at the input of the first amplifier, ERD and MAX(ERD) are the ER degradation and a maximally permissible value for the ER degradation, respectively, and GD and MAX(GD) are the gain degradation and the maximally permissible gain degradation, respectively.

4. Method according to claim 1, 2 or 3, characterised in that the optical power of the help signal is chosen in such a manner that the power of the combined signal at the input of the first amplifier is substantially constant.

5. Method according to any of the claims 1-4, characterised in that the help signal is a noise signal generated by an optical noise source.

6. Method according to claim 5, characterised in that the modulated sigal is a signal within a first narrow wavelength band, and that the noise signal is a signal having a wavelength band, hereinafter to be referred to as noise band, which encloses the first wavelength band.

7. Method according to claim 6, characterised in that, prior to the combination with the modulated signal, the noise signal is filtered in an optical filter for suppressing the first narrow wavelength band in the noise band.

8. Method according to claim 7, characterised in that the optical filter also filters the portion of the noise band above the first narrow wavelength band from the noise signal.

9. Method according to claim 7, characterised in that the optical filter also filters the portion of the noise band below the first narrow wavelength band from the noise signal.

10. Method according to any of the claims 1-4, characterised in that the modulated signal is a signal within a first narrow wavelength band, and that the help signal is a signal within a second narrow wavelength band having a power which is, at any rate approximately, equal to the power of the modulated signal.

11. Method according to any of the claims 1-4, characterised in that the modulated signal is an optical signal within a first narrow optical-wavelength band, and that the help signal is a continuous-wave signal within a second narrow optical-wavelength band outside the first wavelength band.

12. An optical system for long-distance transmission of intensity-modulated optical signals according to the method of any of the claims 1-9, comprising

- an optical-transmission line,
- an optical transmitter and an optical receiver connected to opposite ends of the transmission line for transmitting an intensity-modulated optical signal, hereinafter referred to as modulated signal, along the transmission line, and for receiving the modulated signal, respectively,
- a row of one or more cascaded semiconductor optical amplifiers, included at mutual distances in the transmission line,

- an optical-noise source for generating an optical-noise signal having a wavelength spectrum which lies within the amplifier band of the optical amplifier or amplifiers, and

- optical combining means located in the transmission line between the optical transmitter and the first optical amplifier in the row of optical amplifiers, for combining the modulated signal and the noise signal.

13. Optical system according to claim 12 wherein, between the optical-noise source and the combining means, there is included an optical filter for filtering out at any rate the first narrow wavelength band in the noise signal.

14. Optical system according to claim 12 or 13, wherein the help signal is optically separable from the modulated signal and, in the transmission line between the last amplifier in the row of optical amplifiers and the receiver, there are included optical separating means for separating the noise signal and the modulated signal.

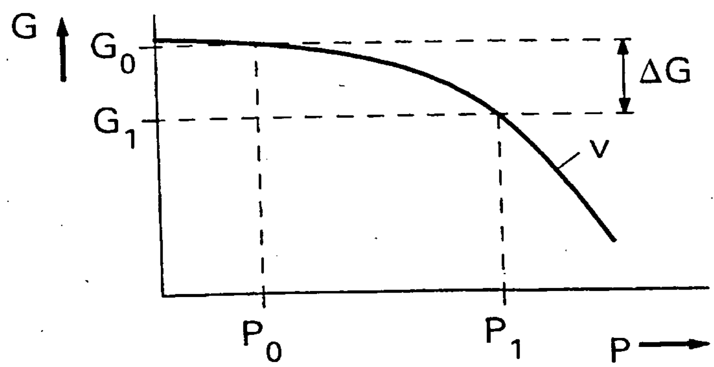

FIG. 1

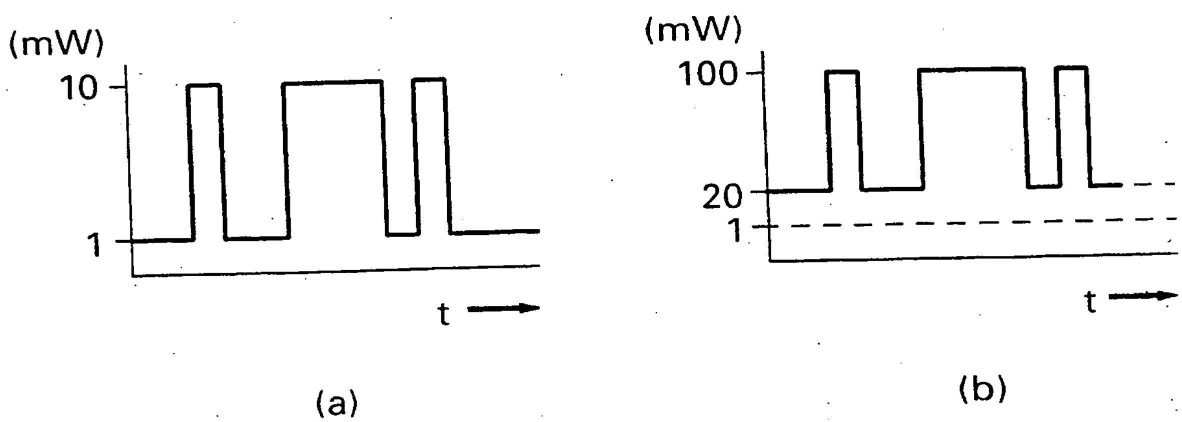

FIG. 2

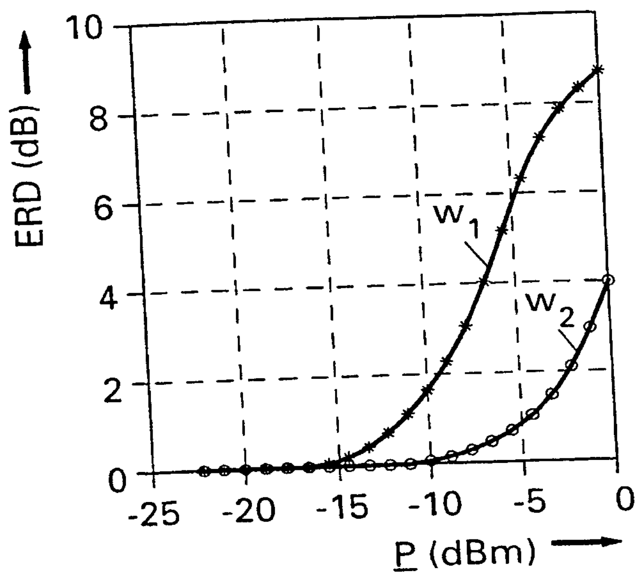
10
8
6
4
2
0
-25
-20
-15
-10
-5
0
ERD (dB)
P (dBm)
w1
w2

FIG. 3

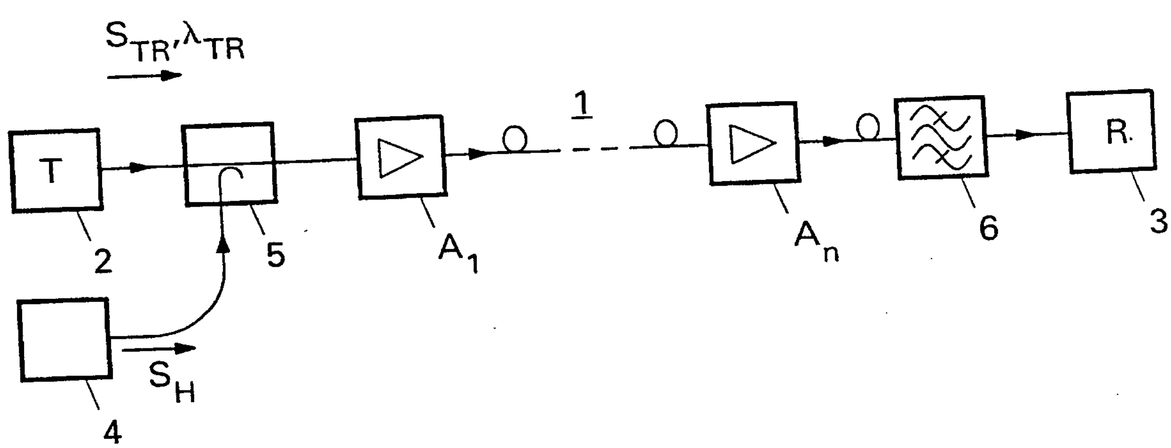
S_TR, λ_TR
T
R.
1
2
5
A1
An
6
3
4
S_H

FIG. 4

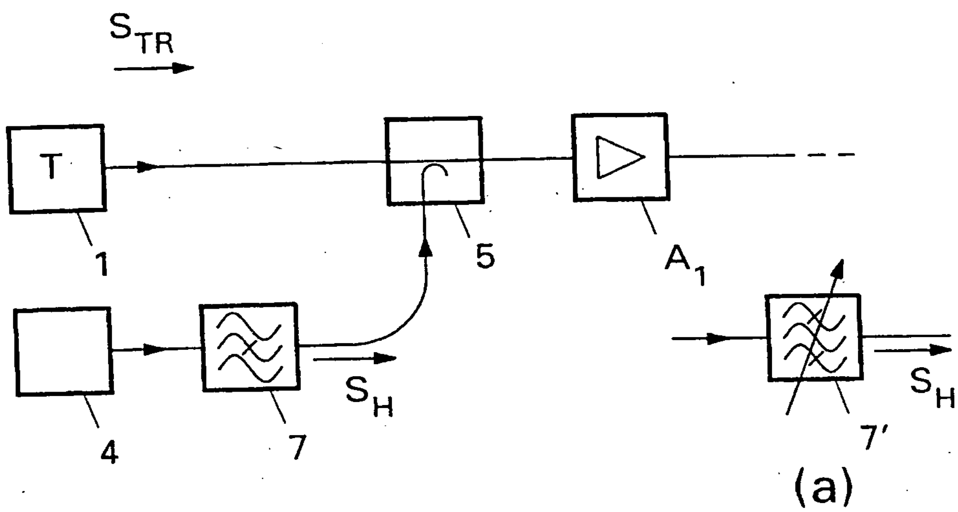
S_{TR}
T
1
5
A_1
4
7
S_H
7'
S_H
(a)

FIG. 5

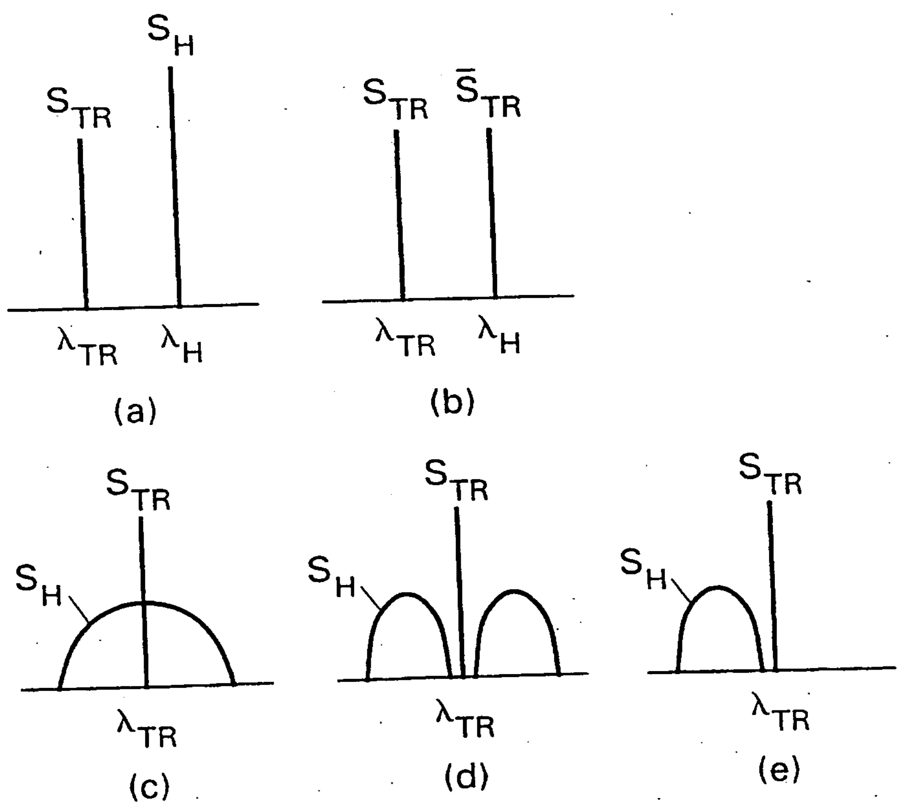
S_H
S_{TR}
λ_{TR}
λ_H
(a)
S_{TR}
$\bar{S}_{TR}$
λ_{TR}
λ_H
(b)
S_{TR}
S_H
λ_{TR}
(c)
S_{TR}
S_H
λ_{TR}
(d)
S_{TR}
S_H
λ_{TR}
(e)

FIG. 6

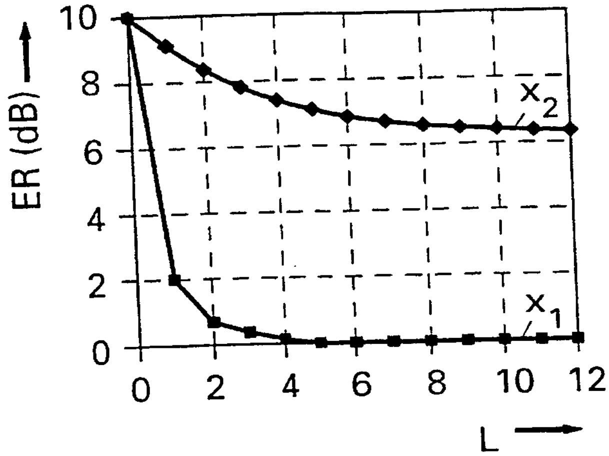
ER (dB)
10
8
6
4
2
0
0
2
4
6
8
10
12
L
x_2
x_1

FIG. 7

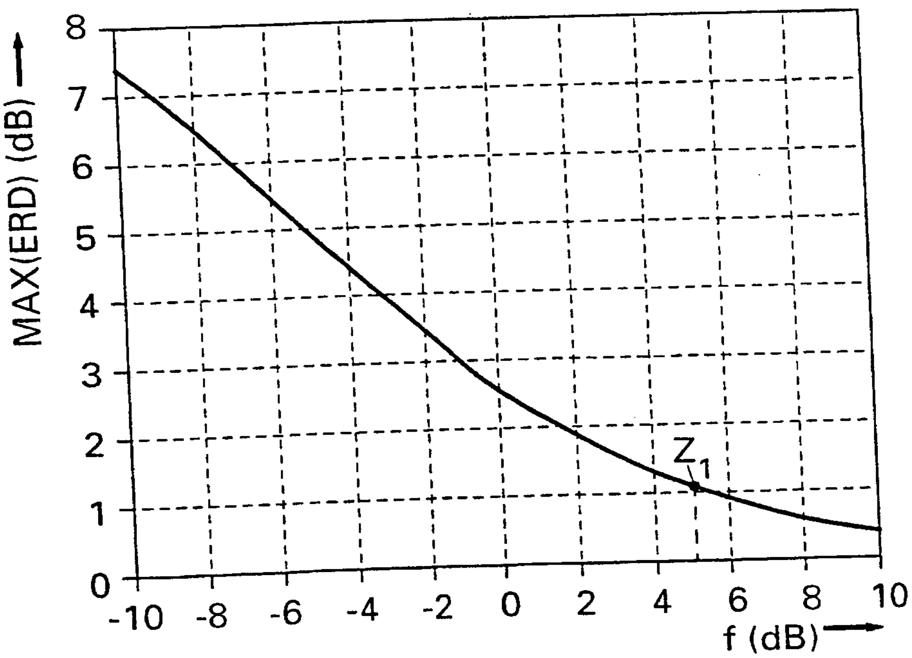
MAX(ERD) (dB)
8
7
6
5
4
3
2
1
0
-10
-8
-6
-4
-2
0
2
4
6
8
10
f (dB)
Z_1

FIG. 8

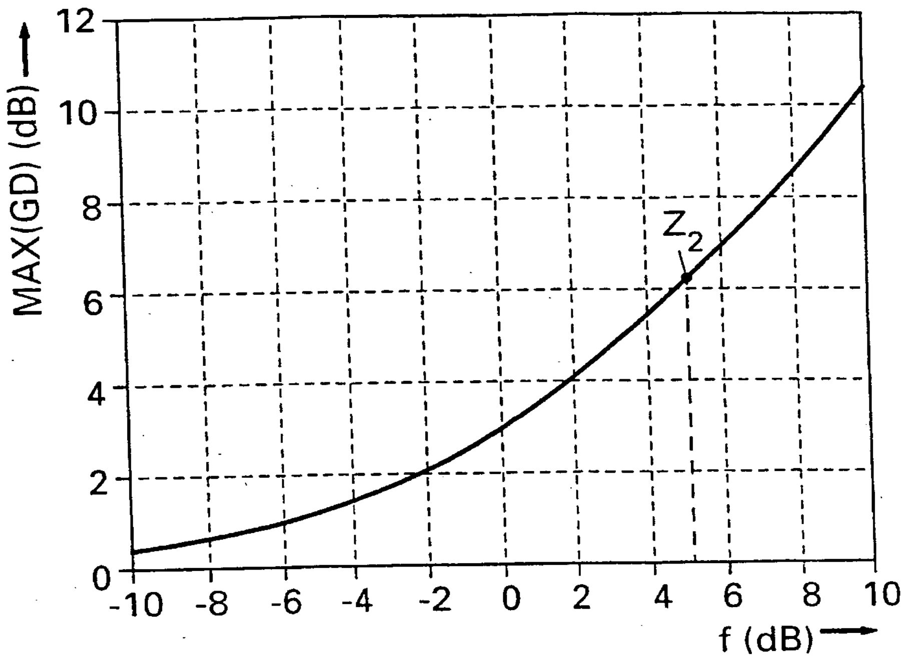
12
10
8
6
4
2
0
MAX(GD) (dB)
Z_2
-10
-8
-6
-4
-2
0
2
4
6
8
10
f (dB)

FIG. 9

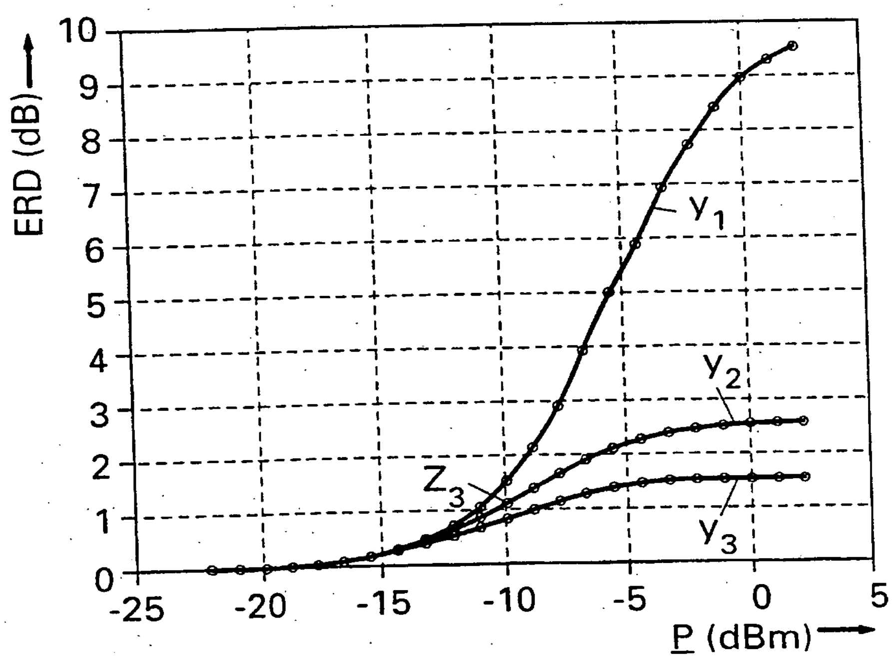
10
9
8
7
6
5
4
3
2
1
0
ERD (dB)
y_1
y_2
y_3
Z_3
-25
-20
-15
-10
-5
0
5
P (dBm)

FIG. 10

INTERNATIONAL SEARCH REPORT

Inte. ɔnal Application No
PCT/EP 97/06961

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 H04B10/17 H01S3/25

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 H04B H01S

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	EP 0 572 890 A (CSELT CENTRO STUDI LAB TELECOM) 8 December 1993 cited in the application see abstract; figure 1 see column 2, line 33 - column 3, line 4 see column 3, line 11 - line 53 ---	1,10-14
A	EP 0 247 834 A (BRITISH TELECOMM) 2 December 1987 see column 1, line 56 - column 2, line 7 see abstract; claim 1; figure 3 ---	1,2,4, 10-14
A	US 5 264 960 A (GLANCE BERNARD) 23 November 1993 see column 1, line 44 - column 2, line 3; claims 1,4,6; figures 2,5,6 --- -/--	1,2,4, 10-14

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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"A" document defining the general state of the art which is not considered to be of particular relevance

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"&" document member of the same patent family

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Date of the actual completion of the international search	Date of mailing of the international search report
15 May 1998	26/05/1998

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Goudelis, M

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5 455 710 A (TAKEDA TOSHIYUKI) 3 October 1995 see abstract; figures 1-8 -----	1,10-14

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INTERNATIONAL SEARCH REPORT

Information on patent family members

Inte onal Application No
PCT/EP 97/06961

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